

# MICROSCOPIC IDENTIFICATION AND SOURCING OF ANCIENT EGYPTIAN PLANT FIBRES USING LONGITUDINAL THIN SECTIONING\*

K. BOROJEVIC† and R. MOUNTAIN

*Boston University—Archaeology, 675 Commonwealth Ave, Boston, Massachusetts 02215, USA*

*Plant fibres and the artefacts constructed from them often remain overlooked in the archaeological record because of their poor survival and the problems related to the precise identification of the species to which the fibres belong. The goal of this study was to design a simple and accurate method of identifying archaeological plant fibre sources. Twenty-two fibre samples from two sets of ancient Egyptian botanical artefacts were examined under both a stereomicroscope and a compound microscope, and compared to a large reference collection and to previously published research. By examining longitudinal thin sections of the ancient plant specimens, we identified plant fibres from the following species: Hyphaene thebeica, Cyperus papyrus, Desmostachya bipinnata, Imperata cylindrica, Phragmites australis and Linum usitatissimum. Our identification of these plant fibres reveals essential information about the materials used for producing ropes, baskets, sandals, mats and fabric. The results of this study demonstrate the value of longitudinal thin sectioning and light microscopy as a major means of identifying the source material of botanical artefacts, and advance our knowledge of ancient Egyptian plant exploitation as well as the associated technologies involved in constructing these types of artefacts.*

**KEYWORDS:** LIGHT MICROSCOPY, LONGITUDINAL THIN SECTIONS, FIBRE, PLANTS, EGYPT

## INTRODUCTION

Humans have constructed cordage, basketry, matting, textiles and other artefacts using plant sources since prehistory (Hardy 2008). Unlike ceramics or lithics, organic materials are susceptible to decay and rarely survive outside dry or anaerobic conditions. When conditions are favourable for the preservation of organic materials, botanical artefacts dominate the archaeological assemblage (Collins 1937; Adovasio *et al.* 2007; Jolie and McBrinn 2010). For example, fibre artefacts outnumber stone tools 20:1 in dry caves (Taylor 1966). Similarly, at waterlogged sites often more than 95% of the recovered material culture remains are made from fibre and wood (Croes 1997). The activities of entire groups of people may remain obscured from history if perishable artefacts are not recovered and fully analysed (Baumhoff 1957; King 1975; Adovasio 1977, 1986; Barber, 1994; Wendrich 1999; Soffer *et al.* 2000; Drooker 2001; Adovasio *et al.* 2007; McBrinn 2010). The prevalent and diverse artefacts created from certain organic materials, although perishable, are very important for the study of past cultures. Therefore, the study of ancient plant materials used for the production of these artefacts is essential to our understanding of ancient resources, technologies and the people who created and used them

\*Received 18 January 2011; accepted 7 February 2012

†Corresponding author: email boro@bu.edu

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(Adovasio 1977; Teeter 1987; Carr and Maslowski 1995; Wendrich 1999, 2000; Drooker 2001; Kemp and Vogelsang-Eastwood 2001; Acs *et al.* 2005).

This study of ancient Egyptian plant fibres was initiated as on-site analysis of macroplant remains during the investigations of the ancient Egyptian harbour of Mersa/Wadi Gawasis (WG) on the Red Sea, which dates to the Middle Kingdom (Bard and Fattovich 2007). Of particular interest was the identification of the source of plant fibres of the cordage from Cave 5—the ‘Rope Cave’, which contained a large number of ropes—previously published by Veldmeijer and Zazzaro (2008). The study was expanded to include the laboratory analysis and identification of the plant fibres of the artefacts from the ancient Egyptian collection of the Museum of Fine Arts (MFA), Boston, Massachusetts.

Provided in this paper are detailed descriptions of the simple preparation of longitudinal sections, microscopy techniques used and photomicrographs of the six plant species that we identified from Egyptian archaeological samples and the comparable specimens from the reference collections. The results are discussed in the light of the use of different plant materials and the place of origin of different artefacts made using plant fibres in ancient Egypt, in particular at the Mersa/Wadi Gawasis site on the Red Sea.

#### PLANT FIBRE PROCESSING

Plant sources used in the production of different artefacts often undergo different methods of processing. Depending on the plant source and the type of fibre, various desired processing techniques are employed in the preparation and extraction of plant fibres, such as drying, retting, beating, cooking and combing. The techniques used in the production of the artefact itself also vary and involve many processes, such as twisting, spinning, plating and weaving (Floriano 1990; Wendrich 1999). The determination of the exact plant source becomes more complicated when similar species from the same family of grasses (Poaceae) or sedges (Cyperaceae) are used for the production of similar artefacts, such as string or ropes. Every stage in this complex manufacturing sequence, from acquiring the raw material from living plants to the final product and its abandonment, impacts the diagnostic anatomical features of the plant material used. Drying processes may result in the compression or condensing of different plant tissues and features such as the vascular bundles. Retting or cooking of the material extracts many of the components, such as starch, and also including other compounds such as lignin and cellulose that give plant tissue its rigid structure. Both epidermal and ground tissues are removed or greatly reduced during fibre extraction processing, often destroying the diagnostic cell features. All of these processing and manufacturing techniques, in addition to various post-depositional processes, affect the preservation of the organic matter and often make the precise identification of the ancient plant material difficult.

#### PREVIOUS STUDIES

Many of the previous studies of perishables have focused on the manufacturing techniques, including studies of the technological aspects of ancient Egyptian cordage basketry and footwear (cf., Wendrich 1999, 2000, 2007; Veldmeijer and Zazzaro 2008; Veldmeijer 2009a,b). Because of the difficulties associated with the precise identification of plant sources, even well-preserved botanical fibres or artefacts sometimes remained unidentified (e.g., Nadel *et al.* 1994; Smith 2003). In the case of other samples, conclusive species identification has required more than a decade after the initial discovery of the artefact (e.g., Acs *et al.* 2005). Even *Anatomical identi-*

fication of some ancient Egyptian plant materials published by Greiss in 1957, containing black and white images and anatomical descriptions of 17 different species used by the ancient Egyptians, is out of print and very difficult to access. The classical volumes on plant anatomy only briefly mention the historical uses of some of the fibrous plants. They provide detailed descriptions of anatomical features examined on recent material (cf., Metcalfe 1960, 1971; Tomlinson 1961; Esau 1965, Evert and Eichhorn 2007); however, many of the descriptions of anatomical features are based on cross-sectional views, which are often not preserved and/or visible in the ancient materials.

A number of studies have successfully employed light microscopy (LM) as a major technique in plant fibre identification (Greiss 1949, 1957; Ryan and Hansen 1987; Florian 1990; Brinkkemper and van der Heijden 1999; Shimony 1999; Waly 1999; Gordon and Keating 2001; El Hadidi and Hamdy 2011).

Newer technological developments, such as scanning electron microscopy, ancient DNA sequencing, and Fourier transform infrared spectroscopy (FTIR), have provided new tools for the study of archaeological materials. Several previous studies on plant fibre identification have taken advantage of these technologies. Catling and Grayson (1982) studied botanical fibre morphology using primarily scanning electron microscopy for the purpose of identification in forensic settings. Jakes *et al.* (1994) used optical microscopy, scanning electron microscopy (SEM), infrared microscopy and energy-dispersive X-ray microanalysis to study plant fibres in a comparative collection assembled for fibre identification in prehistoric eastern North American textiles. Brinkkemper and van der Heijden (1999) used SEM in addition to LM to identify fibres of botanical remains of the ancient Egyptian artefacts studied by Wendrich (1999). Garside and Wyeth (2003) found that the species of botanical fibres used in textiles could be identified using FTIR spectroscopy. While these newer methods are sometimes necessary when the plant fibres are exceptionally small or degraded, they are expensive and time-consuming, and usually cannot be performed on site.

## MATERIALS AND METHODS

### *Archaeological samples*

Two sets of archaeological samples consisting of numerous specimens from desiccated fibre artefacts were analysed in this study: (1) 10 samples from the site of Mersa/Wadi Gawasis (WG); and (2) 12 samples from the ancient Egyptian collection of the Museum of Fine Arts (MFA), Boston, Massachusetts (Table 1; Figs 1–12).

Ten analysed botanical samples come from known contexts from the ancient Egyptian harbour of Mersa/Wadi Gawasis on the Red Sea, which dates to the Middle Kingdom (Table 1; Figs 2, 3, 7, 9, 11 and 12). Gawasis is an ancient harbour site, approximately 23 km south of the modern port of Safaga, dating to *c.* 3800 BC. From this ancient harbour, state-organized seafaring expeditions set out on extended voyages to Punt, a distant land in the southern region of the Red Sea (Bard and Fattovich 2007). These expeditions returned with many exotic products, such as gold, incense, ebony, ivory, plants and wild animals (Kitchen 1993; Shaw and Nicholson 1995; Boivin and Fuller 2009).

The site consists of the eight rock-cut galleries or caves discovered to date and a large production area on the slope below. The galleries served as storage facilities and work areas, and contained extraordinarily well-preserved desiccated organic material, including cedar ship timbers, cordage (coils of rope), cloth and cordage fragments, emmer spikelets, plant parts (grass

Table 1 A list of the identified fibrous plant species from 22 analysed desiccated samples from ancient Egyptian artefacts from the Museum of Fine Arts, Boston (MFA), and the Mersa Wadi Gawasis site, Egypt (WG)

Sample number	Description	Collection	Provenience	Plant family	Species	Artifact image figure number	Photomicrograph figure number
1	Fragment of rope	MFA 97.882	Deir el-Bahri?	Cyperaceae	<i>Cyperus papyrus</i> culm	1	16 (a), 17 (a)
2	Rope (thick)	MFA Eg Inv 4690	Deir el-Bersha	Cyperaceae	<i>Cyperus papyrus</i> culm		and 17 (b)
3	Rope yarn from (Cave 3)	WG	39 A1 SU1 (Cave 3)	Cyperaceae	<i>Cyperus papyrus</i> culm	2	
4	Rope from a coil (Cave 5)	WG	'Rope Cave' (Cave 5)	Cyperaceae	<i>Cyperus papyrus</i> culm	3 (a) and 3 (b)	16 (b)
5	Knotted 'gauze' cloth	MFA 15-4-426	Deir el-Bersha	Linaceae	<i>Linum usitatissimum</i>	4	
6	Woven cloth	WG	Tomb 10A	Linaceae	<i>Linum usitatissimum</i>		
7	Fragmented twined bag (?)	MFA Eg Inv 4639	Deir el-Bersha	Poaceae	<i>Desmostachya bipinnata</i> leaf	5	19
8	Basket with three doum palm nuts and string	MFA 72.4748a	Unknown	Areaceae	<i>Hyphaene thebaica</i> leaf	5	13 (a)
9	String in the basket	MFA 72.4748	Unknown	Poaceae	<i>Desmostachya bipinnata</i> culm	5	
10	Twined bag (small)	MFA 72.4755	Unknown	Areaceae	<i>Hyphaene thebaica</i> leaf	6	14 (a)
11	Fragments of a coiled basket	MFA 15-4-434	Deir el-Bersha	Poaceae	<i>Imperata cylindrica</i> leaf sheath	4	20 (a)
12	Twined bag (?) large	MFA Eg Inv 4595	Unknown	Poaceae	<i>Desmostachya bipinnata</i> leaf	7	
13	Mat fragment (?)	WG	65 E4 SU27	Poaceae	Cf. <i>Desmostachya bipinnata</i> leaf		
14	Sandal sole	MFA 72.4759	Unknown	Areaceae	<i>Hyphaene thebaica</i> leaf	8	15
15	Sandal sole coil	WG	39 under T64	Cyperaceae	<i>Cyperus papyrus</i> culm	9 (a) and 9 (b)	
16	Sandal strap	WG	39 under T64	Linaceae	<i>Linum usitatissimum</i>	9 (a)	22 (a)
17	String for the brush	MFA Eg Inv 4581	Unknown	Poaceae	<i>Desmostachya bipinnata</i> leaf	10	18 (a)
18	Brush (whisk-type)	MFA Eg Inv 4581	Unknown	Poaceae	<i>Desmostachya bipinnata</i> leaf	10	
19	Leaf sheath: 'small grass sheath'	WG	65 A23 SU19	Poaceae	<i>Desmostachya bipinnata</i> leaf sheath	11 (a)	
20	Leaf sheath: 'large grass sheath'	WG	39 B2 SU1 (Cave 3)	Poaceae	<i>Imperata cylindrica</i> leaf sheath	11 (b)	
21	Monocotyledon culm	WG	65 E4 SU27	Cyperaceae	<i>Cyperus papyrus</i> culm		
22	Reed fragment	WG	61 B23	Poaceae	<i>Phragmites communis</i>	12	21 (a)



Figure 1 Rope (*C. papyrus culm*), Deir el-Bersha, © 2011 MFA Boston (Sample 2).



Figure 2 Yarn of a rope (*C. papyrus culm*), WG Cave 3 (Sample 3).

sheaths) and insect remains (Ward and Zazzaro 2010). Below the human-made galleries in the coral terrace was a production area including hearths, ceramic vessels, conical bread moulds, platters, mats and numerous ceramic sherds, along with charred grains of emmer and barley (Bard and Fattovich 2007; Bard *et al.* 2007). Macrobotanical remains, including artefacts made from fibrous plants, were collected at the site, inside and outside the caves, during the 2008–11 winter field seasons and analysed on site (Borojevic 2007, 2010). The results for the identified plants and associated pests from one of the galleries, Cave 3, were recently published (Borojevic *et al.*



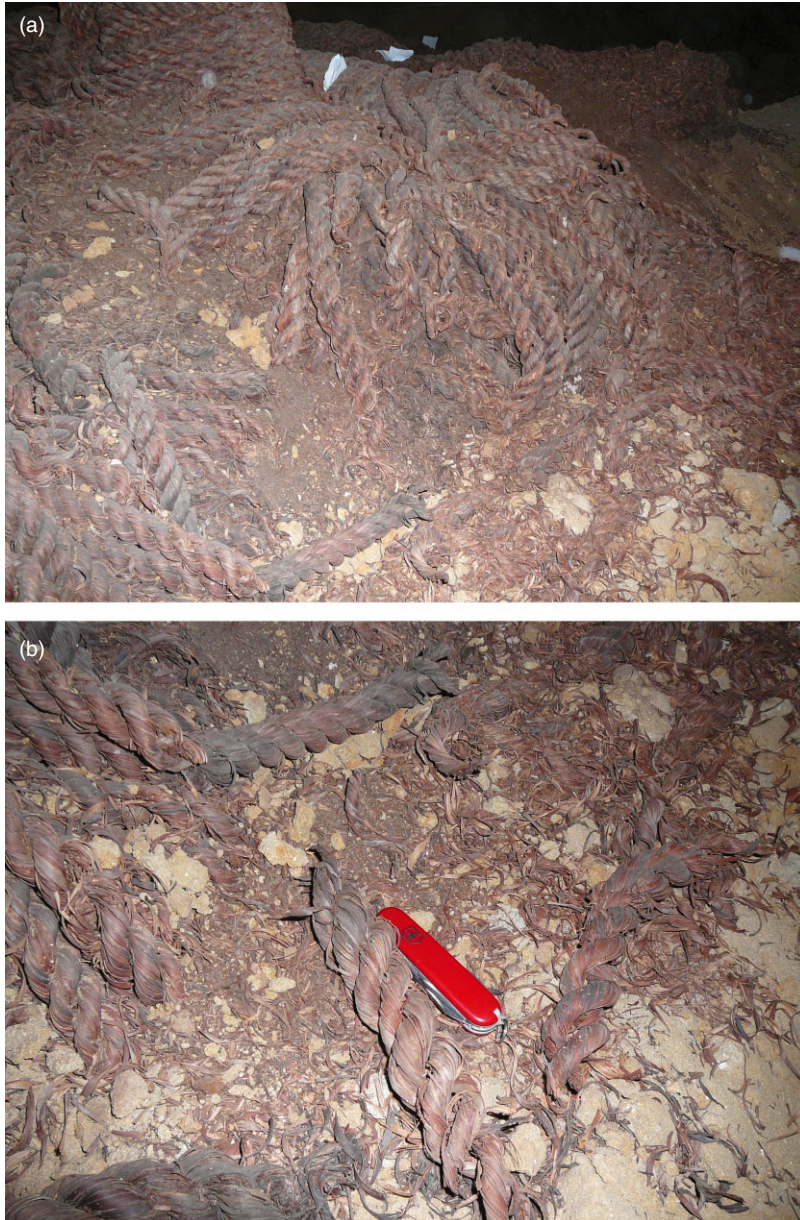


Figure 3 Ropes (*C. papyrus*), WG Cave 5: (a) coils; (b) rope detail (Sample 4).

2010). The analysis of the cordage of Cave 5—the ‘Rope Cave’, which contained a large number of ropes—was previously published by Veldmeijer and Zazzaro (2008). The authors focused on the manufacturing techniques of the ropes, their context and the function of the ropes used for the maritime expeditions. Together with their collaborators, they mentioned some of the likely plant species used to construct the large ropes found in Cave 5 (see our Discussion and Figs 1–3).



Figure 4 Knotted 'gauze' cloth (*Linum usitatissimum*), Deir el-Bersha Tomb 10A (Sample 5) in a fragmented basket (*Imperata cylindrica* leaf sheath), Deir el-Bersha Tomb 13 (Sample 11), © 2011 MFA Boston.

The second set of artefacts consists of 12 samples from the ancient Egyptian collection of the Museum of Fine Arts (MFA), which were also used to validate the accuracy of our identification method of the excavated samples. The artefacts studied included cordage, baskets, bags and a sandal (Table 1; Figs 1, 4, 5, 6, 8 and 10). Small samples were taken from four artefacts from Deir el-Bersha, a necropolis on the East Bank of the Nile in Middle Egypt, dating to the Middle Kingdom, the same period as the archaeological samples from Mersa/Wadi Gawasis on the Red Sea. One sample is from a rope fragment of unknown provenience within the site of Deir el-Bahri, a site on the West Bank of the Nile, opposite the modern city of Luxor and probably dated to the New Kingdom. The remaining seven samples, from the ancient Egyptian collection of the MFA, were of unknown provenience.

### Reference collection

Species identifications were made using previously published sources of ancient Egyptian and Near Eastern fibres and a comprehensive reference collection.

The following published sources were consulted to determine what types of plant materials were available at the time, or have been found in the archaeological record in Egypt and the wider region of the Near East: Greiss (1957), Tächholm (1974), Ryan and Hansen (1987), Teeter (1987),





Figure 5 Basket (*H. thebaica* leaf) (Sample 8) and string fragments (*Desmostachya bipinnata* culm), unknown provenience, © 2011 MFA Boston (Sample 9).

Nadel *et al.* (1994), Schick (1998), Waly (1999), Wendrich (1999, 2000), Ertuğ (2006), Lipshchitz (2007) and de Moulins and Phillips (2009).

On the basis of the published sources, our reference collection included thin sections of the specimens of the following 16 plant species commonly used as fibrous plants by the ancient Egyptians: *Hyphaene thebaica* (L.) Mart. (doum palm), *Phoenix dactylifera* L. (date palm); *Cyperus papyrus* L. (papyrus), *Cyperus alopecuroides* Rottb. (foxtail flatsedge), *Cyperus rotundus* L. (nutgrass), *Cyperus schimperianus* Steud. (no common name); *Juncus acutus* L. (spiny rush); *Juncus arabicus* (Asch. & Buchenau) Adamson (no common name), *Juncus rigidus* Desf. (bitter rush), *Arundo donax* L. (giant reed), *Desmostachya bipinnata* (L.) Stapf. (halfa grass), *Imperata cylindrica* (L.) P. Beauv. (halfa grass), *Phragmites communis* Trin. (common reed), *Saccharum spontaneum* L. (wild sugarcane), *Ceruana pratensis* Forssk. (garawan) and *Linum usitatissimum* L. (common flax).

The reference contained three different types of specimens: (1) samples of present-day species collected near the site of Mersa/Wadi Gawasis on the Red Sea and from nearby Wadi Gasus; (2) modern samples collected from within the United States, in Massachusetts and Arizona; and (3) historical samples of the species obtained from the Harvard Herbaria (H.H.), Cambridge, Massachusetts.





Figure 6 Twined bag (*H. thebaica* leaf), unknown provenience, © 2011 MFA Boston (Sample 10)—scale 1 cm.

The terminology used in the anatomical descriptions of the plant tissues of the identified specimens is primarily based on the anatomical study of some ancient Egyptian plant materials by Greiss (1957).

### *Microscope analysis*

*Stereomicroscope analysis* Each archaeological sample and specimen from our reference collection was examined using a stereomicroscope and photographed with an attached digital camera. First, the macroscopic surface of the fibrous plant was examined for distinctive features, including ribs and nodes, as they can be quite useful at the beginning of the identification process; in particular, the samples were examined for the presence of nodes on the fibre plants. While nodes are usually present in the grass species (Poaceae), they are rarely found in sedges (Cyperaceae). This preliminary examination of desiccated material, while not adequate for precise identifications, allowed us to rule out a great number of other possible plant species.

*Thin-section preparation and light microscope analysis* To examine the important cellular features of the epidermis using a light microscope, slides were made of each specimen. Longitudinal thin-section slides were made of each archaeological and reference sample, except for Samples 5, 6 and 16, as well as of the reference sample of *Linum usitatissimum*. The plant material in these samples was thin and translucent enough to be mounted and photographed without sectioning.



Figure 7 *Mat fragment (cf. D. bipinnata leaf), WG 65 A3 SU 27 (Sample 13).*

Because of the disintegration that can occur when attempting to rehydrate ancient desiccated samples (Gordon and Keating 2001), the longitudinal sections had to be made using a dry cutting method. This was performed by holding the archaeological material in one hand, which rested on a hard surface, then taking a razor blade in the other hand and very carefully shaving off a very thin section of the top layer—or epidermis—of the fibrous plant. The thin section was then mounted on a slide, keeping the original orientation, so that the outer side of the fibre (epidermis) was facing upwards. The sample was hydrated with a few drops of water and then covered. Longitudinal sections of the reference materials were made in the same manner for consistency, and all sample slides were properly labelled. All of the slides were later permanently mounted using Entellan® New Rapid Mounting Medium for Microscopy.

Comparisons between the slides of archaeological samples and reference materials were made using a compound (light) microscope (magnification 100×–1000×). Digital images of the slides were made using a polarizing microscope equipped with an attached camera.

*Scanning electron microscopy* Scanning electron micrographs were made of *Cyperus papyrus* from the reference collection and from the MFA specimens of the large ropes. The reference sample had been previously dehydrated at the Harvard Herbaria before cataloguing. Small fragments, approximately 2 × 3 mm, were mounted on a specimen stub using copper tape and then sputter-coated with gold. The SEM micrographs were made at 10 kV with magnifications ranging from 150× to 1000×, at Boston University. The SEM images were compared to the longitudinal thin sections of the same material using a compound (light) microscope.





Figure 8 Sandal sole (*H. thebaica* leaf), unknown provenience, © 2011 MFA Boston (Sample 14)—scale 1 cm.

## RESULTS

Six different plant species were identified from the 22 ancient Egyptian artefacts (objects) analysed in the study. The results of the analysis are also presented in Table 1. Anatomical features visible in longitudinal thin section and distinctive characteristics of seven plant species are described below. They are accompanied by images of the ancient specimens and the reference counterparts (Figs 13–22). Monocotyledonous species are described first, in the alphabetical order of the families, *Arecaceae*, *Cyperaceae* and *Poaceae*, followed by *Linaceae*. For each plant species, the artefacts and samples that we identified as being made of the particular plant are enumerated.

### *Hyphaene thebaica* (dour palm)

The two palm species (*Arecaceae*), *Hyphaene thebaica* (dour palm) and *Phoenix dactylifera* (date palm), display similar anatomy on the cellular level (Figs 13 and 14). In the leaves, several rows of small rectangular cells overlying the vascular bundles alternate with one to three rows of stomata (often seen as empty spaces in the ancient material). The epidermal cells show a large amount of variation in size, and the subsidiary cells on either side of the stomata are longer and crescent shaped. (The guard cells are typically not visible in the ancient material.) The thick rows alternate with thinner rows of more uniform elongated polygonal cells that cover the veins; however, no stomata are present in these rows (Fig. 13). *H. thebaica* can be distinguished from *P. dactylifera* by the presence of peltate hairs that are visible both macroscopically and microscopically (Figs 14 (a) and 14 (b)), which are absent in *P. dactylifera* (Fig. 14 (c)). If an





Figure 9 Sandal, WG 39 under T64: (a) strap strings (*L. usitatissimum* fibres) (Sample 16)—scale 1 cm; (b) detail of interior sandal coils (*Cyperus papyrus*) (Sample 15).

examined palm specimen is very small and does not have visible peltate hairs, the two palms can be difficult to differentiate (cf., Figs 14 (c) and 15).

Samples 8, 10 and 14 were constructed from *H. thebaica* leaves (doum palm). The samples were from three different artefacts of unknown provenience from the Museum of Fine Arts collection. Both the interior and exterior strands from a coiled basket (Fig. 5) were identified as doum palm, as were the fibres of a small twined bag (Fig. 6), and the interior bundles and exterior sewn strands used for a sandal sole (Fig. 8). The coiled basket (Fig. 5) made of doum palm leaves contained three doum palm fruits and a string made of *Desmostachya bipinnata* culms.



Figure 10 Brush and strings (*D. bipinnata* leaf), unknown provenience, © 2011 MFA Boston (Samples 17 and 18)—scale 1 cm.

### *Cyperus papyrus* (*papyrus*)

Papyrus, a member of the Cyperaceae family, has a distinctive and characteristic cell pattern. In the longitudinal thin section of *Cyperus papyrus* culm from the reference collection, two cell types were visible. Narrow rows of between three and six long, elongated thin-walled cells alternate with broader rows of elongated or polygonal cells with thick densely pitted walls. The wider rows typically contain a single row of stomata. The subsidiary cells are elongated and have thickened walls. These types of narrow thin-walled cells, row patterns and single rows of the characteristic elongated stomata are features of *Cyperus papyrus*, distinguishing it from other *Cyperus* species—for example, *C. rotundus*, *C. schimperianus* and *C. alopecuroides*—which were also used in ancient Egypt (Greiss 1957). The *C. papyrus* species was identified in our ancient samples (Fig. 16).

The scanning electron micrographs taken of a reference sample of *C. papyrus* (Fig. 17) showed the long rows of stomata that are characteristic of the species; however, the rows of cells of varying lengths that accompany the rows of stomata are more visible in the longitudinal thin sections (Fig. 16) than in the SEM micrographs (Fig. 17 (a)). The vascular bundles, discernible in the cross-section, were not identifiable to the species level from the SEM image either (Fig. 17 (b)).

Six different samples in this study were identified as papyrus (*C. papyrus*). Samples 1, 2, 3 and 4 were all various types of ropes made from papyrus culms or stems (Figs 1–3). Rope from Deir el-Bersha (Sample 2; Figs 1 and 16 (a)) is identical to the ropes from Mersa/Wadi Gawasis (Sample 4; Figs 3 and 16 (b)). The interior parallel bundles of a coiled sandal from Mersa/Wadi Gawasis were identified as papyrus culms (Sample 15; Fig. 9). The exterior strands of the sewn





Figure 11 Raw material: (a) 'small grass sheath' (*D. bipinnata* leaf sheath), WG39 B2 SU1 (Sample 19); (b) 'large grass sheath' (*I. cylindrica* leaf sheath), WG Cave 3 (Sample 20)—scale 1 cm.

sandal were not microscopically examined, but there were probably made of palm leaves. A long piece of raw plant material from Mersa/Wadi Gawasis was also papyrus (Sample 21).

#### *Desmostachya bipinnata* (halfa grass)

Two species of grasses (Poaceae) *Desmostachya bipinnata* and *Imperata cylindrica*, both commonly known as halfa grasses, have distinct differences in overall size and morphology of their lamina/sheath junctions that can be seen at the macro-level. However, the two species are very similar on the cellular level. Both display thick rows of long, rectangular, pitted, thick-walled cells, intercalated with shorter thick-walled suberized (cork) cells and small silica cells (Figs 18–20), covering fibrous stands. These rows alternate with similar rows that contain stomata. Stomata have triangular subsidiary cells (Metcalf 1960, 149). The similarities





Figure 12 Raw material, reed with nodes (*Phragmites communis culm*), WG 61 B23 (Sample 22)—scale 1 mm.

render differentiation between the species difficult, especially when working with individual plant specimens only a few cells thick. According to Greiss (1957, 127, fig. 12A), there are two major cellular features of *Desmostachya bipinnata* leaves that distinguish it from *Imperata cylindrica*. *D. bipinnata* has round and circular silica cells throughout the plant, and a greater number of prominent ‘aiguillons’ or spikes (prickle hairs) along the epidermis of the leaf blade (Fig. 19). Various authors differ in the description of the silica cells and the presence or absence of hairs (macro, micro or prickle) in this species (cf., Metcalfe 1960, 149).

A total of six artefacts was constructed from *D. bipinnata* (*sensu* Greiss): four from leaves, one from the culms and one from the leaf sheath. Sample 7 (Fig. 11 (a)) is an unmodified *D. bipinnata* leaf sheath found in Cave 3 at Mersa/Wadi Gawasis (provisionally labelled a ‘small grass sheath’). Another five artefacts made of *D. bipinnata* were from the MFA collection. A brush (Fig. 10) made from *D. bipinnata* leaf fibres (Sample 18) was tied with a string also made of *D. bipinnata* leaf fibres (Sample 17). A large twined bag (Sample 12) of unknown provenience, as well as a grass bag from Deir el-Bersha, were made of *D. bipinnata* leaf fibres. A small string (fragments) of unknown provenience (Sample 9) stored in the basket (Fig. 5) was constructed from twisted fibres of *D. bipinnata* culms. The mat fragment from Mersa/Wadi Gawasis (Sample 13; Fig. 7), is made of fibres of the basal part of the leaves of *D. bipinnata* (the epidermis is very degraded).

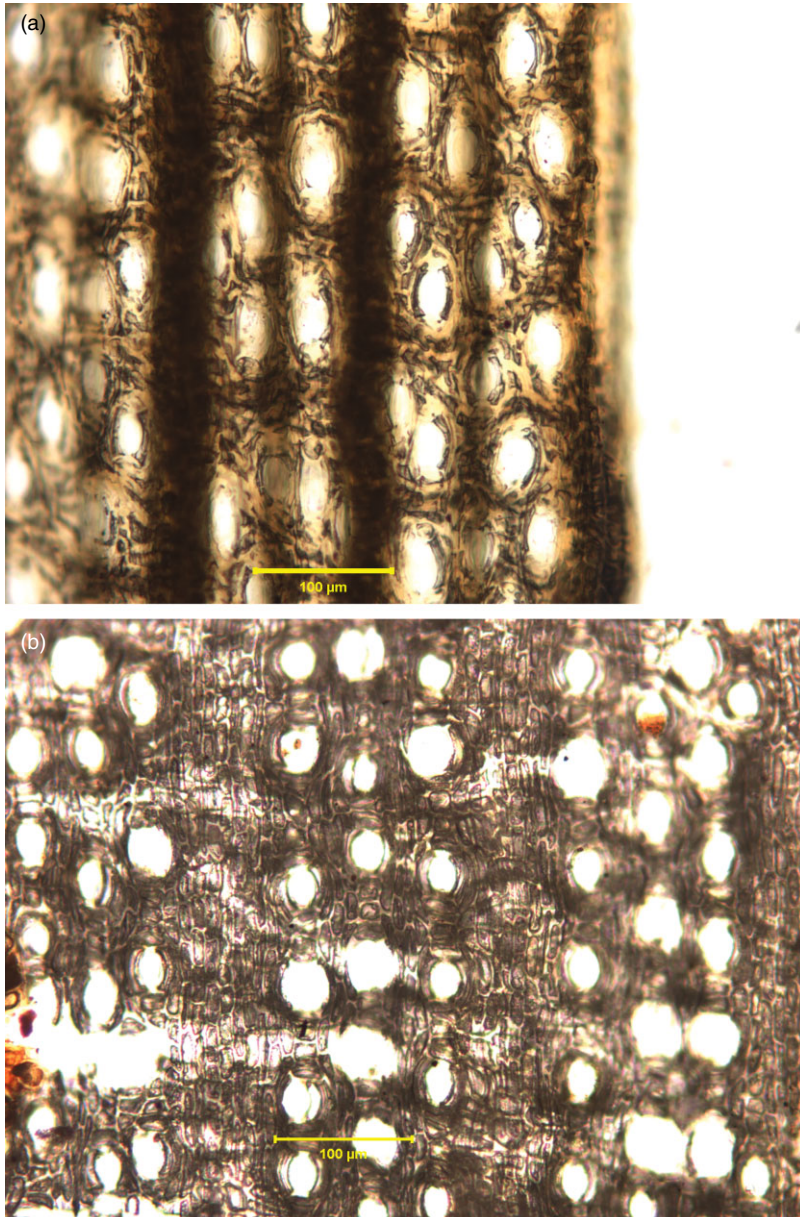


Figure 13 Photomicrographs of longitudinal thin sections of *Hyphaene thebaica*, paradermal sections of leaf epidermis and cuticle: (a) basket (Sample 8); (b) reference collection specimen from the Harvard Herbaria (H.H.).



Figure 14 Image of peltate hairs on *Hyphaene thebaica* leaf with visible dots: (a) twined bag (Sample 10)—scale 1 mm; (b) an image of a hair on a paradermal thin section of cuticle and epidermis of modern *Hyphaene thebaica* leaf (reference collection specimen H.H.); (c) a modern specimen of *Phoenix dactylifera* leaf from Egypt.

### *Imperata cylindrica* (halfa grass)

As mentioned above, distinguishing between *Desmostachya bipinnata* and *Imperata cylindrica* at the cellular level can be difficult. Unlike *D. bipinnata*, however, *I. cylindrica* has square, saddle and markedly dumbbell-shaped silica cells, and possesses fewer, if any, aiguillons on the epidermis of the lamina (Fig. 20).

Samples 11 and 20 were identified as *I. cylindrica*. A leaf sheath of the grass provisionally labelled ‘large grass sheath’ is from Cave 3 at Mersa/Wadi Gawasis (Sample 20; Fig. 11 (b)). The interior fibres from a basket from Tomb 13 at Deir el-Bersha came also from the leaf sheath of *I. cylindrica* (Sample 11; Fig. 4).



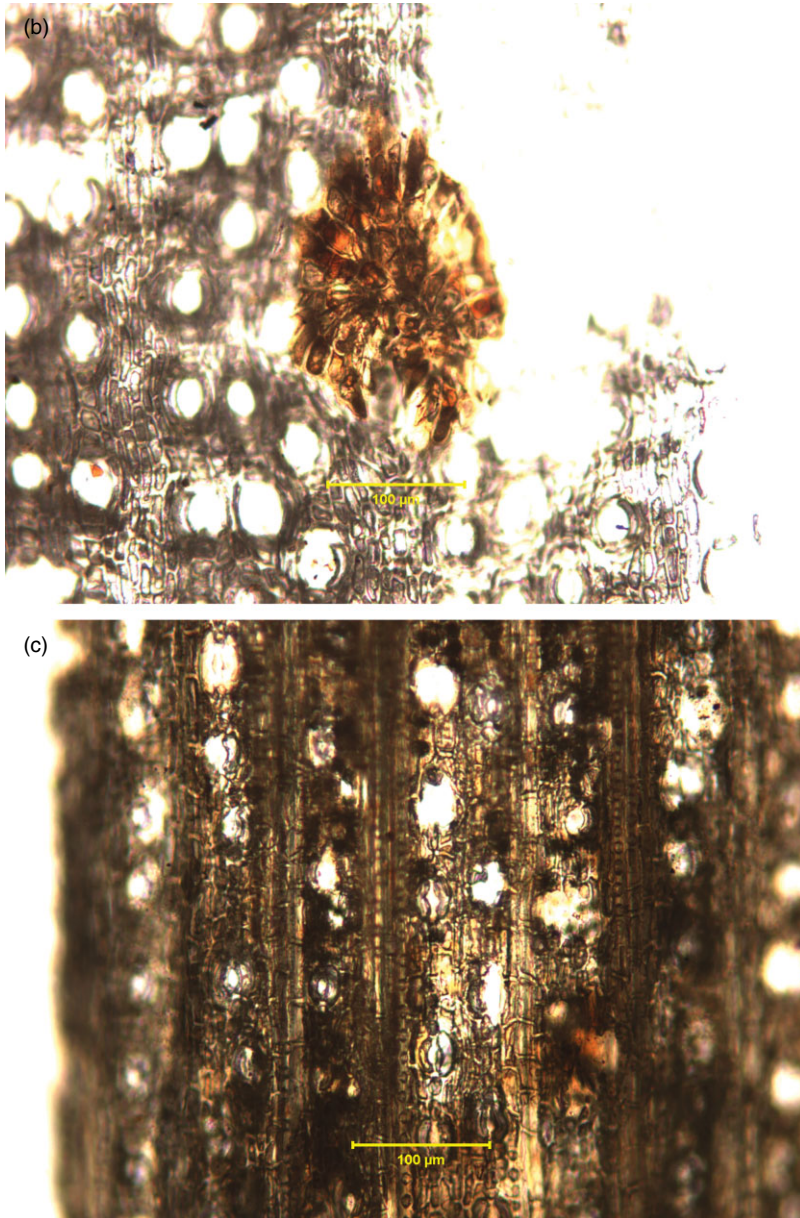


Figure 14 (Continued)

*Phragmites australis* (common reed)

Reeds are members of the family Poaceae that exhibit a characteristic cell pattern. The longitudinal thin section of the culm of *Phragmites australis* is characterized by uniformed rows of very long, narrow, sinuous cells, each bounded by round or crescent-shaped suberized cells or silica

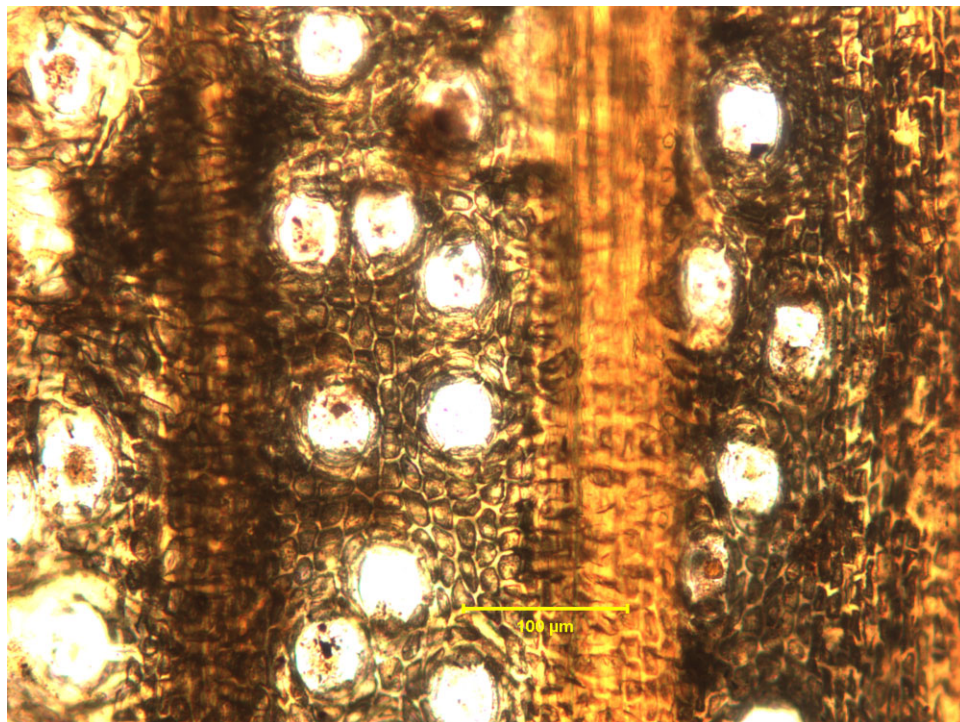


Figure 15 A photomicrographs of a longitudinal thin section of *Hyphaene thebaica* leaf (sandal from MFA, Sample 14). For the reference collection specimen see Figure 13b (above).

cells at either end. No obvious row patterns or stomata are visible in the lower parts of the culm (Fig. 21).

A small fragment of reed culm (Sample 22; Fig. 12) with a prominent node from Mersa/Wadi Gawasis was the only sample in this study identified as *P. australis*.

#### *Linum usitatissimum* (common flax)

Flax (*Linum usitatissimum*) is the only dicotyledonous (eudicot) plant identified among the artefacts in this study. The fibres are cylindrical and slender, with faint striations and cross-markings and tapering ends (Fig. 22). These markings are supposedly the result of stress involved in processing of the fibres (Greiss 1957). The fibres are made up of a single row of very long, narrow, rectangular-shaped cells with thick walls and typically narrow lumen (visible inside the cavity). The cellular structure of flax fibres can be viewed under a compound microscope without the use of thin sectioning.

A small sandal strap (Sample 16; Fig. 9 (a)), a piece of woven cloth (Sample 6) from Mersa/Wadi Gawasis and a piece of knotted gauze-like material (Sample 5; Fig. 4) from Tomb 10 at Deir el-Bersha were constructed from *L. usitatissimum* fibres.

#### DISCUSSION

The results of this study of ancient plant fibres clearly demonstrate the value and significance of the longitudinal thin-section technique and the use of light microscopy for the rapid and accurate



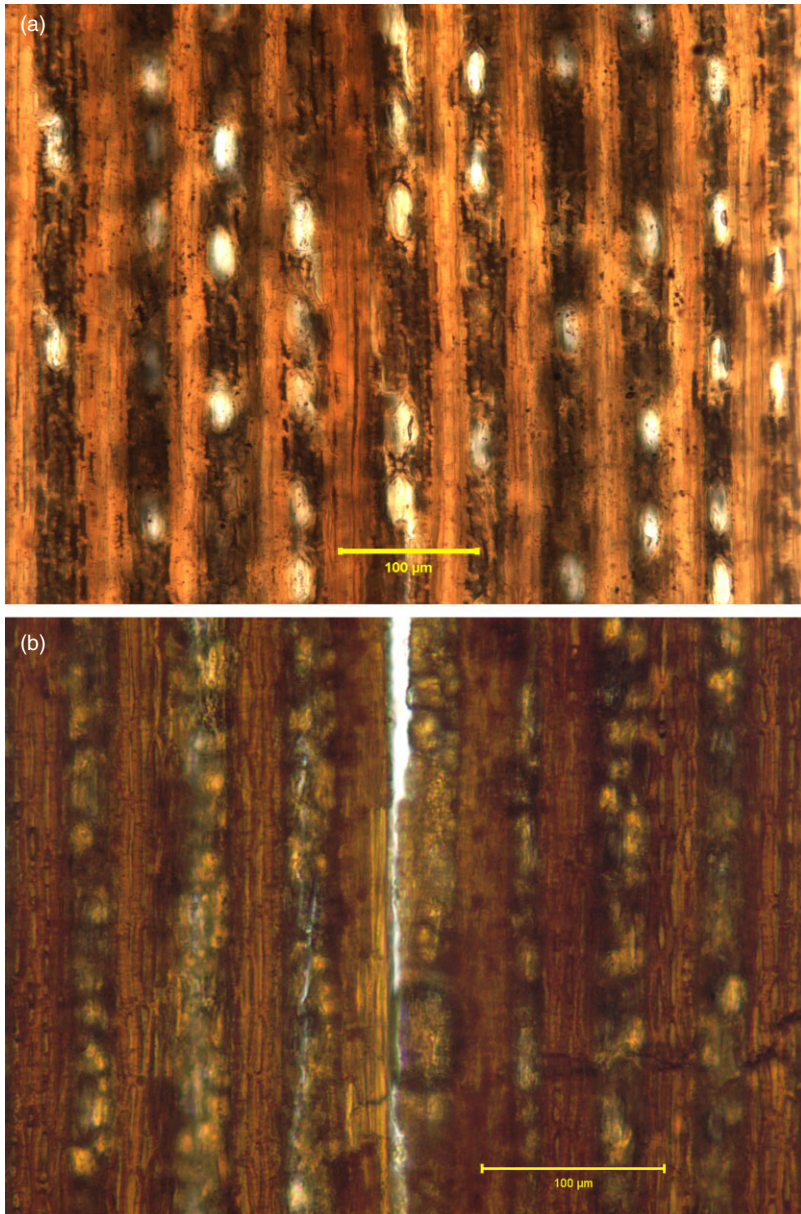


Figure 16 Photomicrographs of longitudinal thin sections of *Cyperus papyrus* culm: (a) rope from MFA (Sample 2); (b) rope from WG Cave 5 (Sample 4); (c) reference collection specimen (H.H.).

identification of plant fibres. Six different plant species from 22 desiccated samples (Figs 1–12) used in ancient Egyptian artefacts were identified on the basis of the fibres' epidermal cell patterns. The slide images of the longitudinal thin sections show clear cellular differences, including characteristic row patterns (Figs 13–22), as well as differences in general cell size and shape, even among closely related species of grasses and palms.



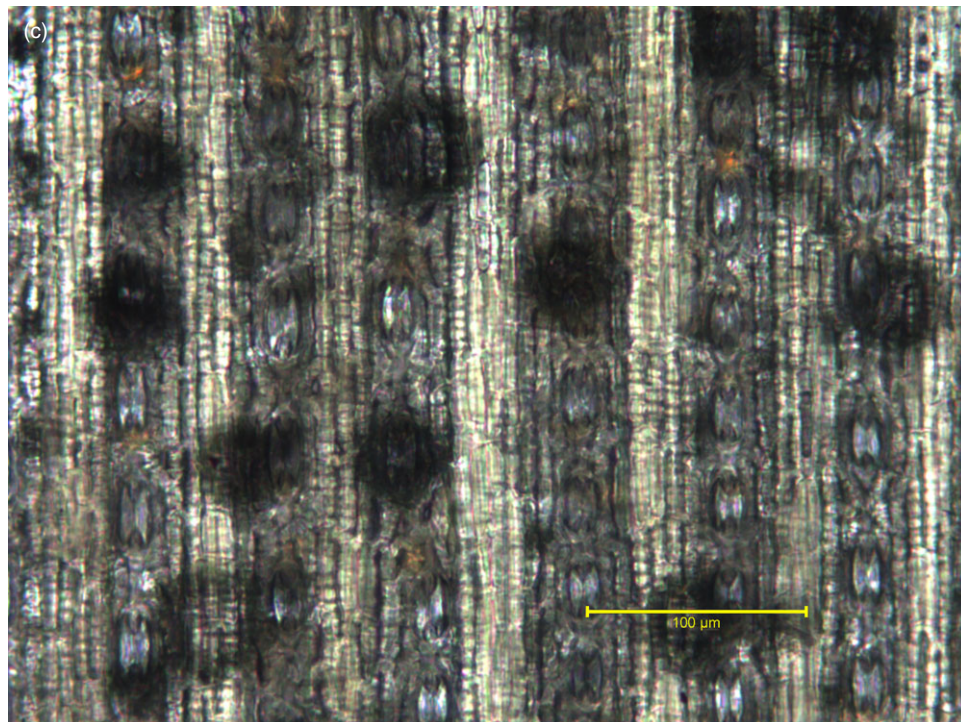


Figure 16 (Continued)

The making of longitudinal thin sections is simple and straightforward. The technique requires minimal supplies and can be performed almost anywhere. While previous studies, including an earlier analysis of the rope sample from Cave 5 at Wadi Gawasis (Veldmeijer and Zazzaro 2008), focused on identification based on cross-sections of fibrous plants, this study utilizes the longitudinal thin section. Cross-sections are more difficult to obtain in ancient desiccated materials due to the brittle nature of the material. The fragile tissue necessitates special preparation for embedding into a medium before thin sectioning and the use of a vacuum chamber (cf., Ryan and Hansen 1987; El Hadidi and Hamdy 2011). This type of sectioning may result in compression of the diagnostic features, such as the vascular bundles (Gordon and Keating 2001). The vascular bundles are often distorted by any previous processing techniques associated with the production of the artefact and can become less discernible in cross-sections (Florian *et al.* 1990).

The vascular bundles visible in cross-section in both Poaceae (Gramineae) and Cyperaceae can appear very much alike and conform to the basic type described by Metcalfe (1960; see also Metcalfe 1971, 23–4). Identification using cross-sections also proved unsuitable for the analysis of Egyptian basketry by Wendrich and colleagues; instead, the analysis of epidermis patterns was employed by Brinkkemper and van der Heijden (Wendrich 1999, 429–40). The preparation of longitudinal thin sectioning is simple and does not necessitate laboratory facilities.

Problems associated with the identification of monocotyledon species using a cross-sectional view without special preparation and embedding of the specimens, we believe, may have led to the misidentification of the rope from Cave 5 at Wadi Gawasis as being made from reeds and not from papyrus (Veldmeijer 2009a). In the detailed study of the cordage manufacture from the

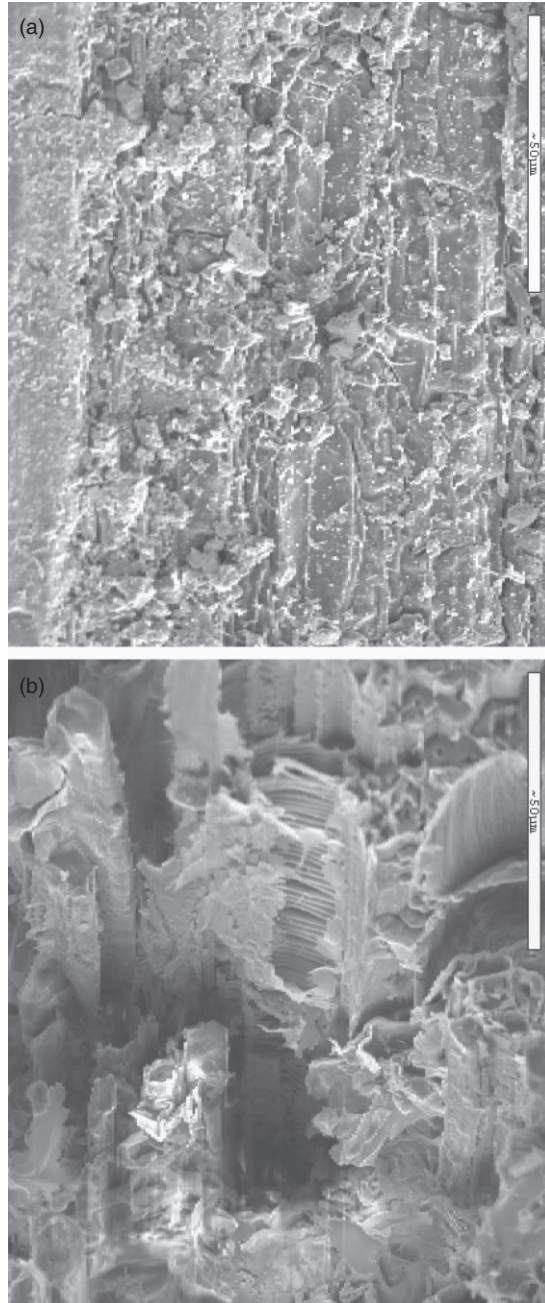


Figure 17 An SEM micrograph of epidermis of *Cyperus papyrus*: (a) longitudinal section; (b) cross-section (Sample 2).

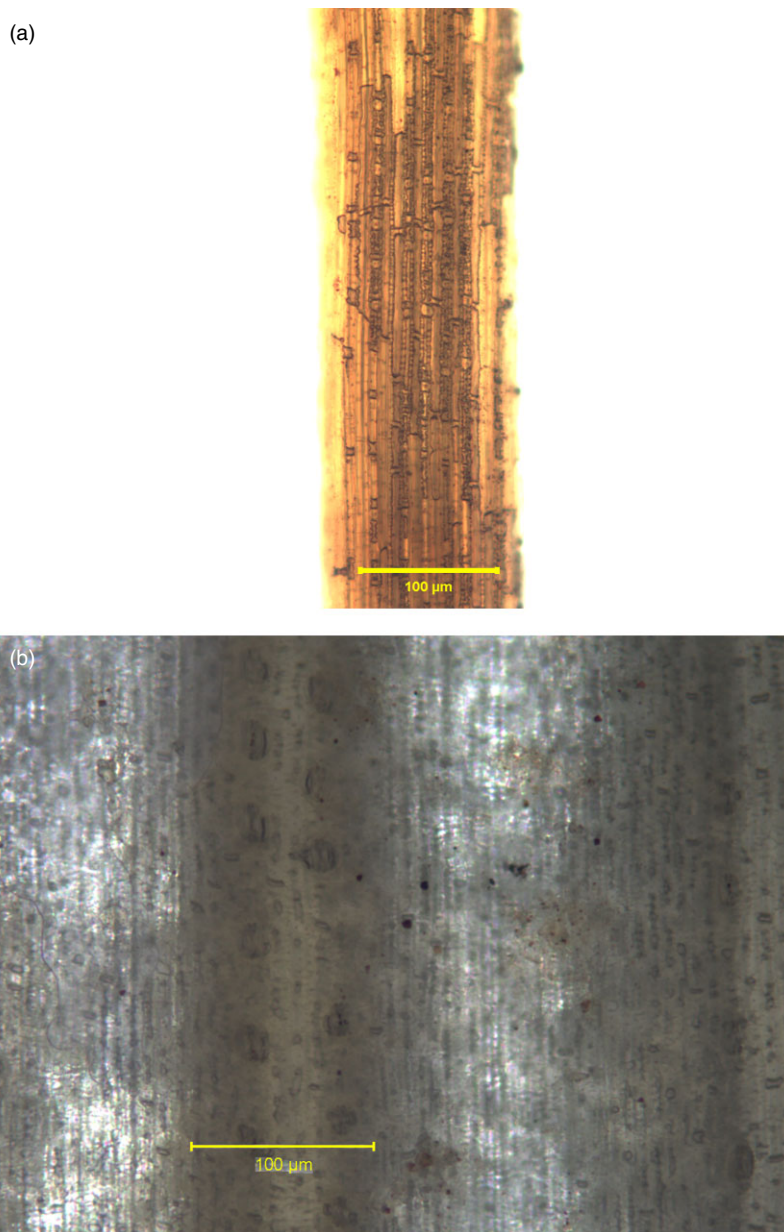


Figure 18 Photomicrographs of longitudinal thin sections of *Desmostachya bipinnata* leaf: (a) brush string (Sample 17); (b) reference collection specimen (H.H.).

'Rope Cave', Veldmeijer and Zazzaro (2008), with their collaborators, suggest that the 'rope' in question was probably constructed from a reed species, either *Arundo donax* or *Phragmites australis*, and not from papyrus *Cyperus papyrus*, as initially suggested by Borojevic (Zazzaro 2007, 192, n. 6). As shown on images of the slides above, *C. papyrus* (Sample 4; Fig. 16 (b))



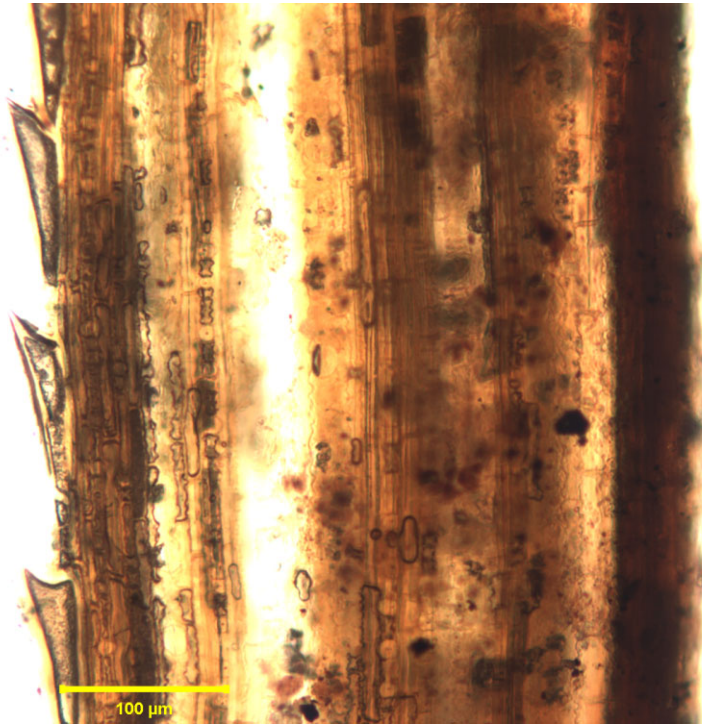


Figure 19 A photomicrograph of *aiguillons* on a longitudinal thin section of leaf from *Desmostachya bipinnata* (bag fragment, Sample 7).

bears little resemblance in longitudinal section to *Phragmites australis* or *Arundo donax* (Figs 21 (a)–(c)). The coils of rope, including Sample 4 (Fig. 3), showed no signs of any of the nodes characteristic of both reed species (see Fig. 12). Instead, the sample most closely resembles *C. papyrus* (Fig. 16 (b)) in its epidermal cell features. Additional samples (specimens) of the ropes from four different coils within Cave 5 at Wadi Gawasis were examined during the 2010–11 field season. All of the ropes appeared identical in construction and were made of papyrus (*C. papyrus*). The identifications of the additional samples demonstrate the importance of analysing the microscopic features of the specimens; in particular, the epidermal cell patterns visible in the longitudinal section, as shown in this paper.

In this study, four of the 22 ancient Egyptian analysed objects were large ropes made of papyrus. Two of the rope samples came from two caves at the site of Mersa/Wadi Gawasis (Samples 3 and 4), the third rope came from Deir el-Bahri (Sample 1) and the fourth from Deir el-Bersha (Sample 2). The thick ropes from Deir el-Bersha (Sample 2) and from Cave 5 at Mersa/Wadi Gawasis (Sample 4) were visibly identical (Figs 1 and 3), having the same thickness, twist directions, twist angle and number of strands. The fact that identical ropes made of papyrus were found at two distant places dating to the Middle Kingdom indicates a possible standardization for making large ropes out of papyrus. Petrie and Griffith (1898) identified cordage made from papyrus at the Old Kingdom cemetery at Deshasheh (Lucas and Harris 1989). Greiss (1957) identified papyrus ropes from the site of Helwan dating to the First and Second Dynasties, in addition to two ropes from different Egyptian museums, one rope dated to the First Dynasty and

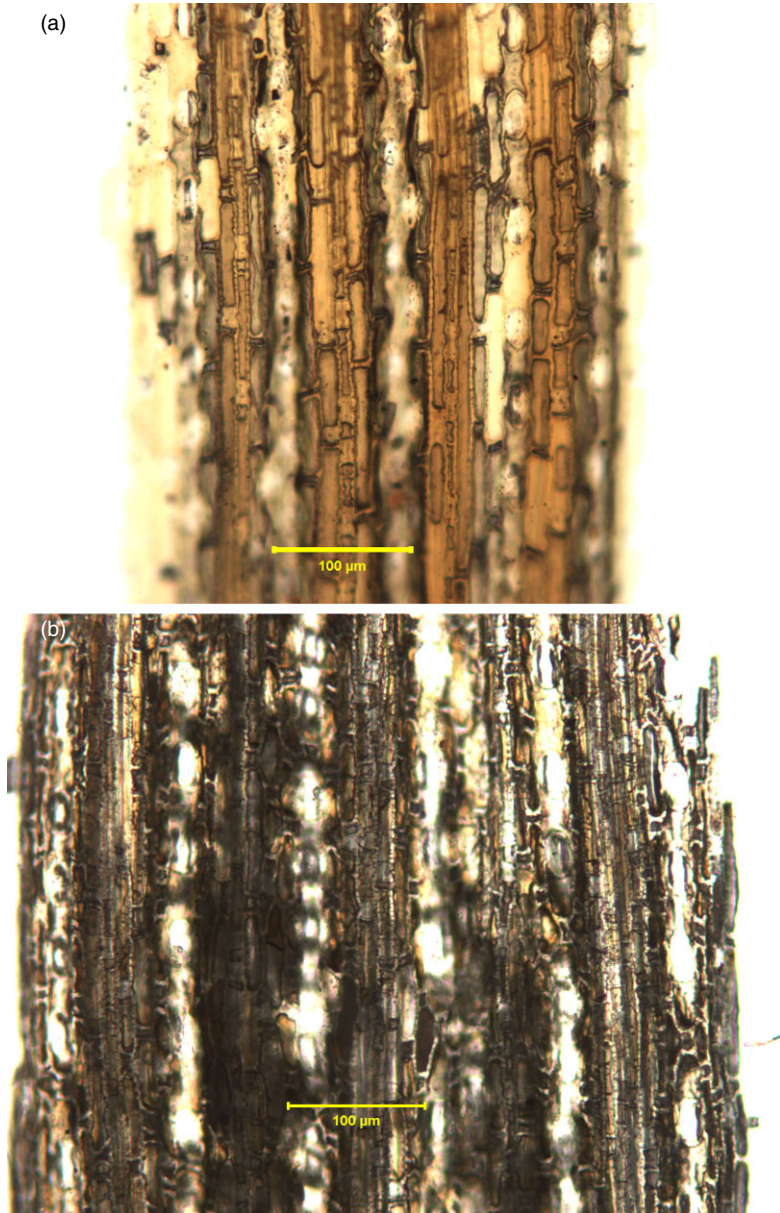


Figure 20 Photomicrographs of longitudinal thin sections of *Imperata cylindrica* leaf sheath: (a) basket (Sample 11); (b) reference collection specimen (H.H.).

another to the Third Dynasty. Papyrus ropes from the Tura caves initially identified by Greiss (1957) were later dated to the Ptolemaic or Roman period. The identification was later confirmed by Ryan and Hansen (1987). From a total of 16 cordage specimens investigated from the ancient Egyptian collection of the British Museum, six were made of papyrus (Ryan and Hansen 1987). Additional evidence comes from a number of tomb paintings, which illustrate rope-making using

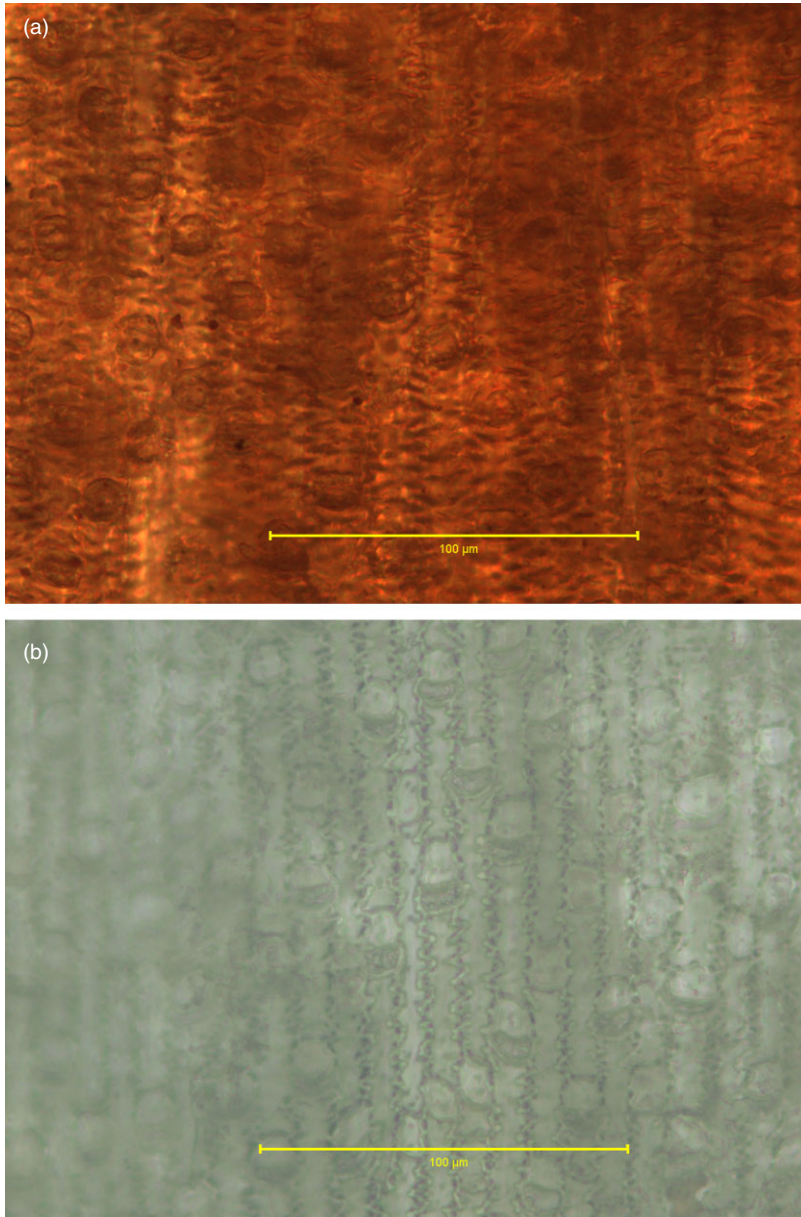


Figure 21 Photomicrographs of longitudinal thin sections of reeds: (a) *Phragmites australis* (raw material, Sample 22); (b) *Phragmites australis* (modern specimen from Egypt); (c) *Arundo donax* (reference collection specimen H.H.).

papyrus plants dating from as early as the Fifth Dynasty and as late as the 18th Dynasty (Davies and Griffith 1900; Mackay 1916; Dunham 1935; Teeter 1987). It is possible that papyrus was the plant of choice for making large ropes, as it is a more pliable material than a stiff reed such as *Phragmites* or *Arundo*, but longer than the halfa grasses. Papyrus grows up to 5 m tall—even occasionally up to 9 m tall—which is taller than halfa grasses (Hughes *et al.* 1992; Leach and Tait



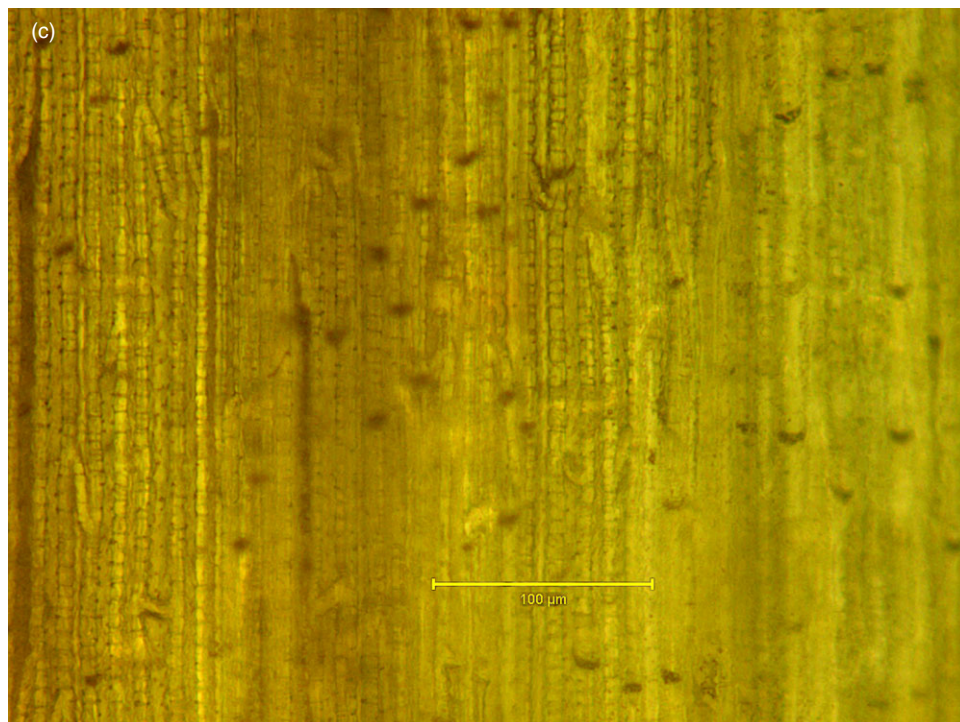


Figure 21 (Continued)

2000) and would provide very long continuous fibres for rope construction. In recent study of nine artefacts dated to the New Kingdom, including baskets, cordage, footwear, bags and fans, not a single one was made of reeds (El Hadidi and Hamdy 2011).

The Egyptian tomb paintings mentioned above also depict the rope-making process, which is shown being performed by men or young boys (Teeter 1987). Ropes were still being made by men, in the same manner as depicted in the ancient Egyptian tombs, at the beginning of the 20th century (Mackay 1916). While other fibre artefacts may indicate the presence of women (Barber 1994; Adovasio *et al.* 2007; McBrinn 2010), the tomb evidence would suggest that the making of large ropes was a male activity in ancient Egyptian times, and could be used as a useful indicator of gender in the archaeological record.

Bohr and Olsen (2011) have analysed the images of the ropes from Mersa/Wadi Gawasis (see also Fig. 2), investigating the ancient art of laying rope from a mathematical perspective. They explain why ropes that appear to be almost identical can be made from very different materials. Maximally rotated strands behave as zero-twist structures and therefore under strain they rotate neither in one direction nor in the other. This is the geometrical property of the ropes; that is, a pitch angle corresponding to the maximally rotated zero-twist structures, which is  $\sim 50^\circ$  for the Mersa/Wadi Gawasis ropes. This explains the unyielding nature of these ropes (Bohr and Olsen 2011).

In our study, fragments of small ropes or strings, and a large twined bag (?) were made of the leaves of halfa grass *Desmostachya bipinnata* and *Imperata cylindrica*. A smaller string fragment and two pieces of a gauze-type textile were made from flax (*Linum usitatissimum*). Leaves of

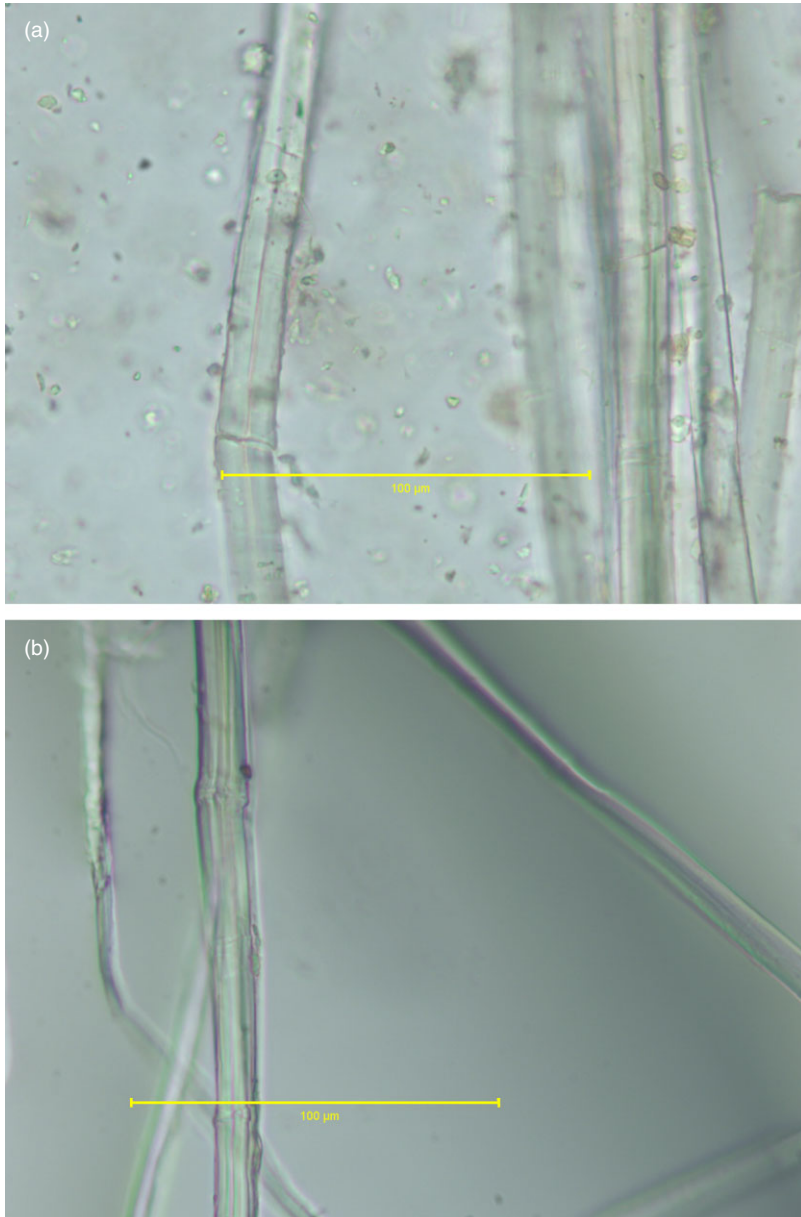


Figure 22 Photomicrographs of longitudinal thin sections of *Linum usitatissimum* fibres: (a) sandal strap (Sample 16); (b) a modern sample from the reference collection.

*Hyphaene thebaica* (doum palm) were used for making baskets, bags and sandals. Some of the artefacts were made using fibres of two or more different plant species; for example, sandals were made of papyrus culms for coils and sewn with palm leaves.

This study demonstrates that the ancient Egyptians used various available plant sources for the manufacturing of artefacts, and often combined several plant species and plant parts in produc-

tion of the same artefacts. In some instances, specific plant materials may have been intentionally used for manufacturing particular products by the ancient Egyptians, particularly papyrus for large ropes. The plant *Cyperus papyrus* grew in the Nile valley in ancient times, and thus the ropes from the sites along the Nile, such as Deir el-Bahri (Sample 1) and Deir el-Bersha (Sample 2), were probably locally made. Papyrus has never been mentioned growing along the Red Sea (Tächolm 1974; Leach and Tait 2000; Zahran and Willis 2009). Thus, the papyrus ropes from the ancient harbour of Mersa/Wadi Gawasis must have been brought from the Nile valley, more than 150 km away, during the Middle Kingdom (c. 3800 BCE). The ropes, rather than large quantities of raw papyrus, were probably brought together with the disassembled ships and other supplies for the maritime expeditions, including linen textiles and sandals.

Reeds (*Phragmites* sp.) still grow in the wadis along the Red Sea and near the site of Mersa/Wadi Gawasis, and must have been much more widely spread and used in pharaonic times. Unprocessed fragments of reed culms were recovered from the site, but the large ropes were not made from the locally available halfa grasses. Presently, there are no halfa grasses—*Desmostachya bipinnata* or *Imperata cylindrica*—to be observed growing around the site, but the ecological requirements and the past distribution of these plants (Tächolm 1974) indicate that they could have been growing around the site in the Middle Kingdom. The recovered leaf sheathes of halfa grasses and culms are further evidence that the raw materials were available around the site of Mersa/Wadi Gawasis and were collected and brought to the site, including the caves. They may indicate that the artefacts constructed from the halfa grasses were made locally, unless they were also brought with other supplies to the harbour.

#### CONCLUSION

Perishable artefacts, when they survive at archaeological sites, are of equal importance to more durable objects and thus should be studied in greater detail. It is important to identify the source material of the artefacts, as this can provide crucial information about present and ancient plant use, ecology, the presence of specialized industries, agriculture, trade and possibly gendered activities. Our results demonstrate that the use of simple light microscopy and longitudinal thin sectioning allows for the accurate and rapid identification of the source material of the desiccated ancient botanical artefacts on site. The method applied in this study is particularly useful when examining botanical fibres of archaeological samples in those countries that do not allow exports of archaeological specimens and where access to SEM is very limited. Furthermore, the SEM used in the laboratory showed less of the cell patterns characteristic of individual species than simple light microscopy of the longitudinal thin sections, both for the reference and the desiccated ancient materials from the museum collection. In contrast, through the use of longitudinal thin sectioning, without any previous preparation such as embedding or coating, six different plant species were identified from 22 desiccated samples from the ancient Egyptian artefacts.

Our study of plant fibres reveals important information about the materials and sources used for producing ropes, baskets, bags, sandals, mats and fabric from various contexts dating to the Middle Kingdom and the New Kingdom. The identified plant sources include commonly used plant fibres in Egypt: papyrus, halfa grasses, doum palm and flax. The plant sources from the ancient harbour of Mersa/Wadi Gawasis consist of fibres of plants that were commonly used in ancient Egypt, some of which do not grow in the Red Sea region, such as papyrus and flax. For the making of large ropes and a sandal, papyrus was the raw material; flax was used for the textiles. These artefacts were probably brought as ready-made products from the Nile valley. Reeds and halfa grasses were locally available and were recovered as a raw material at the site.



Mats made of halfa grasses could have been made locally, unless they were also brought to the harbour from the Nile valley. They provide further evidence for the complexity of supplying and organizing maritime expeditions from this ancient harbour on the Red Sea.

There is great potential in ancient plant fibre analysis to further our understanding of how past cultures interacted with and made use of the plants and their environments. The results demonstrate the feasibility of rapid identification of the desiccated botanical material using minimal equipment on site.

#### ACKNOWLEDGEMENTS

We are grateful to Dr Kathryn Bard, Boston University, and Dr Rodolfo Fattovich, University of Naples 'L'Orientale' for providing us with the opportunity to be part of the Mersa/Wadi Gawasis project and to examine the plant fibres on the site. Funding for our fieldwork in Egypt was by a generous grant from Mrs Wallace D. Sellers. We are thankful to Dr Denise Doxey, Curator of Ancient Egyptian, Nubian and Near Eastern Art, for granting us access to the botanical artefacts from Boston's Museum of Fine Arts Egyptian Collection, and to the MFA Images Department of Intellectual Property for giving us permission to reproduce our images of the selected MFA artefacts. The Undergraduate Research Opportunities Program at Boston University provided the funds to Rebecca Mountain for the laboratory part of the study at Boston. Anlee Krupp, of the Photonics Center of Boston University, made the scanning electron micrographs. Melinda Peters and Walter Kittredge of the Harvard Herbaria provided the material for the reference collection. Janet Kay and Aviva Cormier of Boston University helped with editing of this manuscript. We are grateful to all them for their help and assistance. We are thankful to an anonymous reviewer for the detailed comments regarding descriptions of anatomical features.

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